

Two-component Injection Molding of Molded Interconnect Devices

Jyun-yi Chen, Wen-Bin Young^{*1}

Department of Aeronautics and Astronautics, National Cheng Kung University
Tainan, 70101, Taiwan, ROC

^{*1}youngwb@mail.ncku.edu.tw

Abstract

Molded Interconnect Device (MID) can be defined as an injection-molded plastic part combining with electrical and mechanical functions in a single device. This study is to examine the application of micro injection molding technology to the two-component molding process for the MID fabrication. The process involves the first shot of a plastic component with channel patterns on the surface; while the second shot by micro injection molding technology is applied to fill the channel with the plateable plastics. The effects of the micro injection molding process parameters on filled line width of the two-component MID will be investigated. It is concluded that, for a MID component, the molding conditions must be designed carefully to keep the thickness variation below the allowable value. It is also found from the experiments that the thickness interference may be in the range from 92 μm to 196 μm to have adequate molding at the second shot.

Keywords

3D-molded Interconnect Devices; Two-component Injection Molded; Electroless Copper Plating

Introduction

The printed circuit board (PCB) is used to mechanically support and electrically connect the electronic components together to achieve the function of the electronic product. Due to the miniature technology in the electronic application, it has been considered the possibility of constructing the electrical connecting on the plastic housing directly to eliminate the extra space for a PCB. Molded Interconnect Device (MID) can be defined as an injection-molded plastic part combining with electrical and mechanical functions in a single device. The technology originated in 1980s and was employed to many applications in electronic communication, health care, and automotive industries because of its potential to reduce the number of components and compact in size. Feldmann and Gerhard investigated the problems related to soldering on thermoplastic substrate. Feldmann and Krimi presented two placement systems that enabled

3D PCB with surface mounting devices on inclined planes. Islam, et al. demonstrated how the MID technology can be used for industrial products to achieve shorter process chain and reduce the number of components. Macary and Hamilton introduced the MID process using the laser direct structuring and the existing applications.

The process of MID can be roughly divided into the injection molding of the plastic component and fabrication of the metal traces. The metal traces are served as the electrical circuit on the plastic substrate. There are several major methods for fabrication of the circuit traces on the plastic substrate as two-component injection molding, hot stamping, photo lithography, in-mold circuit film, and laser direct structuring (LDS). The LDS process is the most flexible process that is to apply a laser beam to the traces of a plastic molded component containing metallic particles, followed by electroless deposition of metals. Islam, et al. showed that the success of the LDS process is heavily dependent on the choice of material. In two-component injection molding, the plateable and non-plateable plastics are molded together by injection molding. Metallization process is applied on the plateable plastic to form the circuit traces. The photo lithography can construct the circuit traces on the plastic component by film deposition followed by plating, but is mostly used in the flat circuit patterning. The hot stamping and in-mold circuit film apply the circuit traces directly on to the plastic parts.

This study is to examine the application of micro injection molding technology to the two-component molding process for the MID fabrication. The process involves the first shot of a plastic component with channel patterns on the surface. The second shot by micro injection molding technology is applied to fill the channel with the plateable plastics. The process steps are shown in Fig. 1. On the left hand side, the plastic component is molded with the first molding tool and the molding of the traces is shown on the

right hand side with the second molding tool. In order to study the moldability of the traces on the plastic component, a simple straight channel is used as the trace pattern in this study. Experiments are designed to mold channels on a plastic substrate with different widths from 200 μm to 1000 μm , and the channel depth is set to 500 μm . The effects of the injection molding process parameters on filled line width of the two-component MID will be investigated.

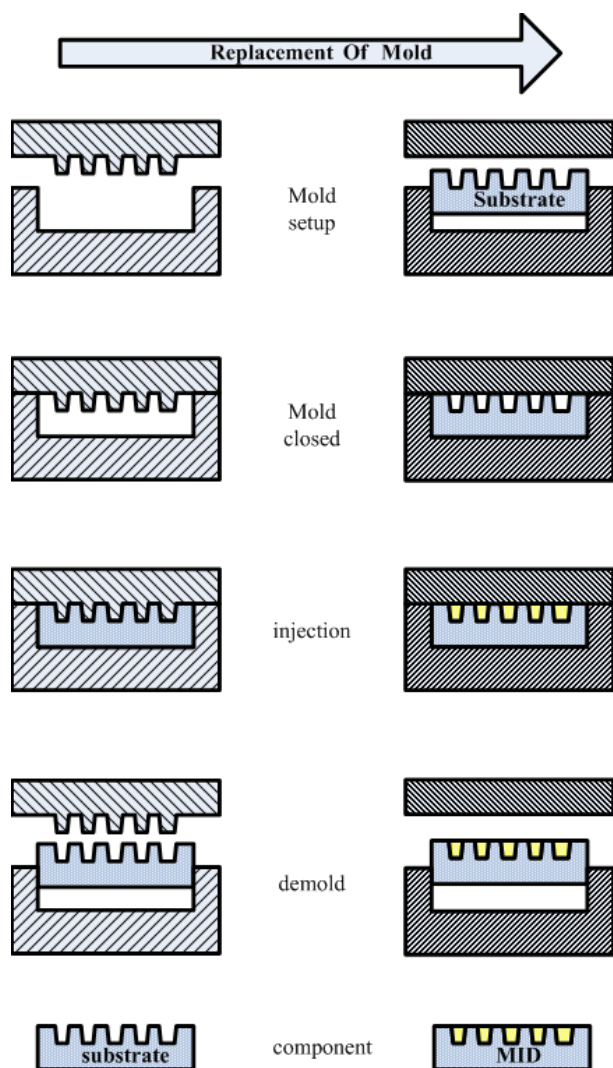


FIG. 1 FABRICATION STEPS OF THE TWO COMPONENT INJECTION MOLDING PROCESS FOR MID

Experimental

The objective of this experimental study is to identify two issues involved in the two-component injection molding. The first is to determine the suitable range for the dimensional interference in the design of the second molding tool. In the two component injection molding, the plastic part will be imbedded into mold during the second shot as shown in Fig. 1. If the plastic part is too thin for the second mold, a flash problem will occur during the injection. On the other hand, if

the plastic part is too thick, the mold cannot be closed without crashing the plastics part as shown in Fig. 2. Therefore, a dimensional interference between the second mold and the plastic part must be carefully designed. In this study, it will be attributed as the thickness interference. The second issue is to investigate the filling length in the channel in the second shot. This will be used as a guide for the design of filling gates in molding a circuit trace in the plastic part.

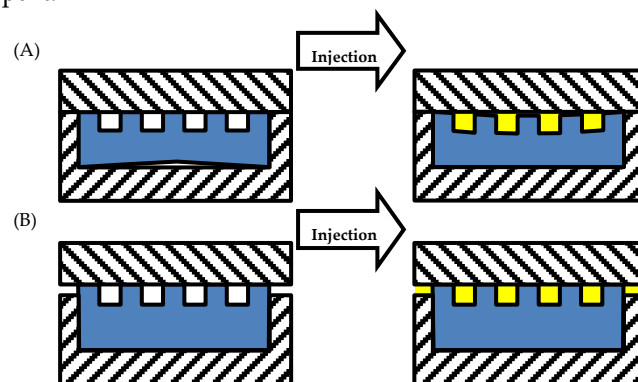


FIG. 2 THE EFFECT OF THE DIMENSION OF THE PLASTIC PART ON THE FILLING OF THE SECOND SHOT. (A) TOO THIN (B) TOO THICK

At the first shot, a two-plate mold is used in this study. The movable mold platen has two rectangular cavities with dimensions in 14x14x3 mm and the fixed mold platen has two rectangular mold inserts with nine channels on the surface as shown in Fig. 3(a). The channels have the dimension of 14 mm in length and 0.5 mm in thickness. Their width ranges from 0.2 to 1 mm by 0.1 mm increment. Another two-plate mold is used for the second shot as shown in Fig. 3(b). The mold has two rectangular cavities with dimensions in 14x14x2.9 mm in the moving side and mold inserts with a flat surface on the fixed side. In the other set of the mold, the cavity height of the first shot mold is changed to 1.5 mm in the subsequent study in order to improve the smoothness of the molded plastic substrate. The cavity height for the second shot mold is changed to 1.374 mm correspondingly.

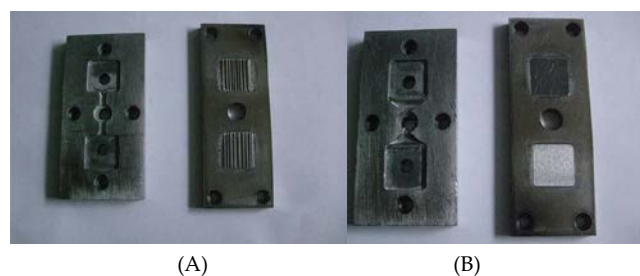


FIG. 3 (A) THE INJECTION MOLDING TOOL FOR THE FIRST SHOT (B) THE INJECTION MOLDING TOOL FOR THE SECOND SHOT

Materials used in the molding experiments are

polycarbonate PC-110 for the non-plateable plastic and ABS PA-727 for the plateable traces (from Chi Mei Corporation, Taiwan). The base process conditions for the first shot are set as: melting temperature is 320 °C, mold temperature is 110 °C, ram speed is 20 mm/s, packing pressure is 80 MPa, packing time is 10 seconds, and cooling time is 10 seconds; while those conditions for the second shot are set as: melting temperature is 230 °C, mold temperature is 90 °C, ram speed is 60 mm/s, packing pressure is 80 MPa, packing time is 10 seconds, and cooling time is 10 seconds. The component after second shot can be plated by electroless plating to deposit the copper on the channel surface. A typical component after metallization is shown in Fig. 4.

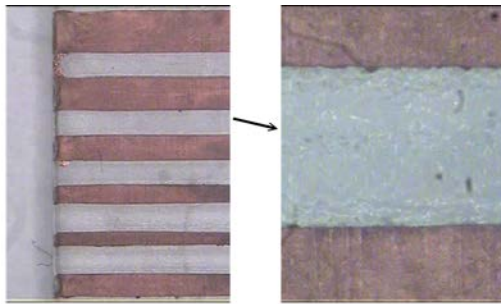


FIG. 4 A TYPICAL COMPONENT AFTER ELECTROLESS PLATING COPPER ON THE CHANNELS

Molding of the Plastic Substrate

As shown in Fig. 2, the interference of the thickness between the plastic substrate and the cavity of the mold in second shot will affect the filling in the channels. In the design of the second shot mold, the cavity height is less than that of the mold in the first shot. If everything is perfect in dimension, 0.1 mm and 0.126 mm thickness interferences are expected for two sets of the molds. However, because of the nature of the plastics, dimension variation is expected in the first shot. Therefore, investigation of the thickness variation of the first molding substrate is performed before start of the second molding.

Due to the molding process, the thickness of the plastic substrate will not be uniform. The thicknesses at nine points (A1 to A9) on the substrate were measured on the molded plastic substrate as shown in Fig. 5. Different packing pressures (from 20 MPa to 160 MPa with 20 MPa in increment) were used for the molding. The resulting thickness on each point is shown in Fig. 6. It is noticed that the thickness at the center of the substrate (A5) is much less than that at the other positions. This is believed to be caused by the knock-out pin at that position. Thickness at the

position far from the gate is generally smaller due to the less packing effect. Also, the thickness is not uniform along the direction perpendicular to the channels, which is attributed to the non-uniform channel structures on the substrate.

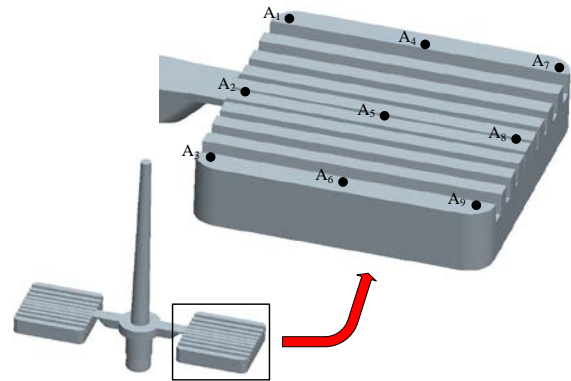


FIG. 5 THE PLASTIC PART OF MID WITH CHANNEL TRACES

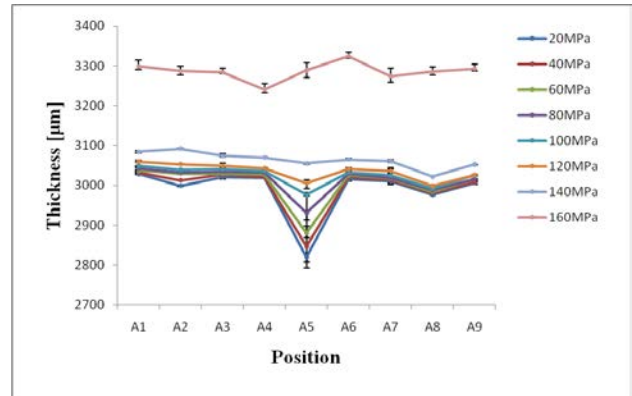


FIG. 6 THICKNESS OF THE SUBSTRATE MOLDED UNDER DIFFERENT PACKING PRESSURES AT DIFFERENT POSITIONS

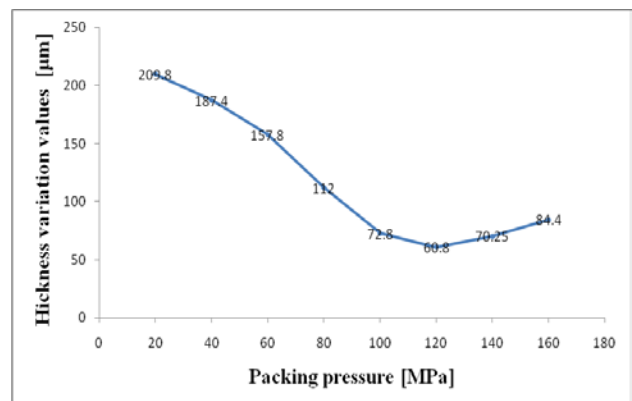


FIG. 7 THICKNESS VARIATION OF THE SUBSTRATE MOLDED UNDER DIFFERENT PACKING PRESSURES FOR A SUBSTRATE OF 3 mm IN THICKNESS

The thickness variation of the substrate is defined as the difference between the maximum and minimum values of thicknesses measured at the nine positions. Figure 7 shows the thickness variation of the substrate molded under different packing pressures. It is

noticed that the thickness variation has the lower value as the packing pressure is around 120 MPa. As the plastic substrate is embedded into the mold for a second shot, a flash problem occurs if the thickness variation exceeds about 100 μm . The material of ABS will flow over the channels and cover the substrate as shown in Fig. 8. Therefore, it is necessary to control the thickness variation in the first shot of the plastic substrate in order to eliminate the flash problem.

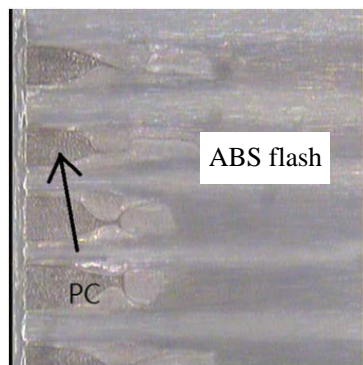


FIG. 8 FLASH OF THE ABS MATERIAL AS THE THICKNESS VARIATION OF THE PC SUBSTRATE IS TOO LARGE

One way to improve the thickness uniformity of the substrate is to reduce the total thickness. Another mold with a smaller cavity height, 1.5 mm, is used for the molding of the substrate. The resulting thickness variation is shown in Fig. 9 under different packing pressures. The thickness variation is quite low as compared to the previous case. It is demonstrated that the thickness of the substrate will affect the uniformity of the molding part. On the other hand, if the thickness of a MID component is selected based on other considerations, the molding conditions must be designed carefully to keep the thickness variation below the allowable value (about 100 μm in this case).

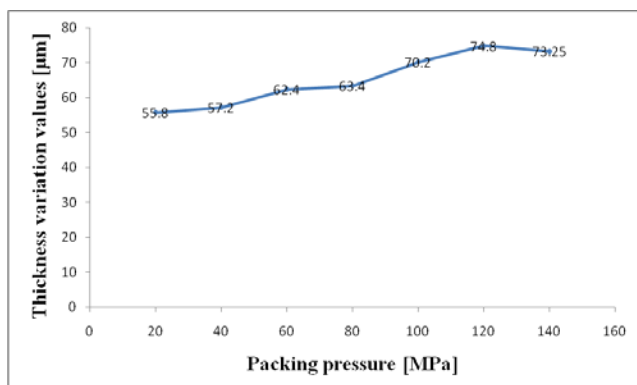


FIG. 9 THICKNESS VARIATION OF THE SUBSTRATE MOLDED UNDER DIFFERENT PACKING PRESSURES BY USING A MOLD WITH CAVITY HEIGHT 1.5 mm

Thickness Interference

The thickness interference is defined as the thickness

difference between the substrate and mold cavity as shown in Fig. 10. In the second shot to fill the small channels for circuit traces, the substrate embedded into the mold cavity usually has a thickness larger than the cavity height to ensure a tight contact with the mold surface. As the mold closes and compresses the surface of the substrate, the channel will change in shape due to the deformation of the surface materials. Before the second shot, the dimensions of the channels at the molded plastic substrate are measured first. Table 1 lists the average value of the channel width at the substrate as compared to the original dimension at the mold.

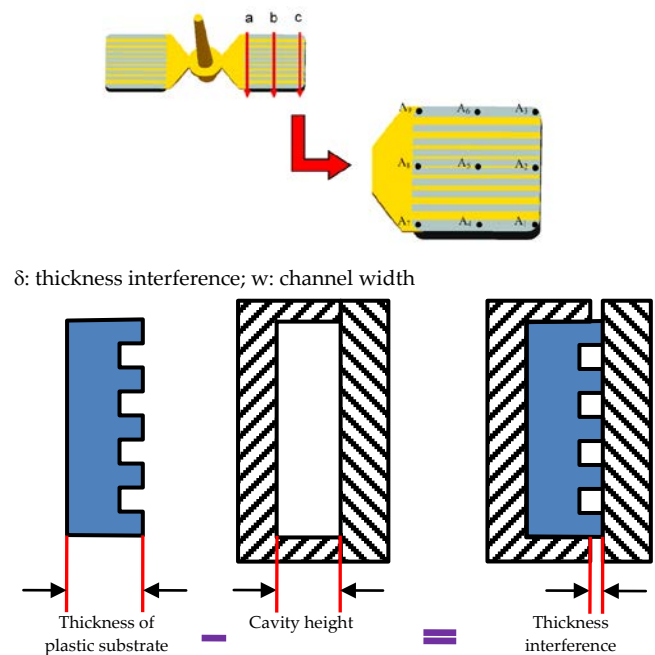


FIG. 10 THICKNESS INTERFERENCE IS DEFINED AS THE DIFFERENCE BETWEEN THE SUBSTRATE AND MOLD CAVITY IN THICKNESS

TABLE 1 THE CHANNEL DIMENSION AT THE MOLDED PLASTIC SUBSTRATE USING THE MOLD WITH CAVITY 14 mm LENGTH

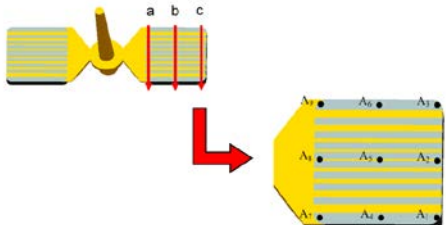
Channel width at the mold	Channel width at the plastic substrate
200 μm	182 μm
300 μm	350 μm
400 μm	421 μm
500 μm	523 μm
600 μm	632 μm
700 μm	715 μm
800 μm	822 μm
900 μm	907 μm
1000 μm	1013 μm

As mentioned earlier, the thickness variation must be smaller than 100 μm to eliminate the problem of flash during the filling. Therefore, only the substrates molded at a packing pressure higher than 100 MPa is

acceptable for the second shot if the designed thickness is 3 mm. For the mold with a cavity in a thinner thickness, 1.5 mm, the resulted substrates molded under different packing pressures can all be used in the second shot. The typical results of the second shot for the channels are listed in Table 2 for the substrate molded under 80 MPa packing pressure and a designed thickness 1.5 mm. The left column shows the channel width of the plastic substrate and the mold cavity (in parentheses). The channel width on the part surface after the second shot will change due to the deformation of the substrate after mold compression. There are nine positions where the thickness interferences are measured (A1-A9). A large value of thickness interference will cause the substrate to deform significantly and leads to the smaller channel width on the surface. If the interference is too large, the channel may deform a lot and close at the surface. It is concluded from the experiments that the thickness interference may be in the range from 92 μm to 196 μm to have adequate molding at the second shot. If the interference is too small, the same flash problem will also occur. As the interference is too large, the mold compression will destroy the channel entirely.

TABLE 2 THE RESULTING CHANNEL WIDTH AFTER SECOND SHOT AND THE THICKNESS INTERFERENCE

Channel width of the plastic substrate	along a	$\delta(\mu\text{m})$	along b	$\delta(\mu\text{m})$	along c	$\delta(\mu\text{m})$
1013(1000)	1025	164 (A ₉)	900	184 (A ₆)	850	196 (A ₉)
822(800)	845		715		710	
632(600)	655		535		500	
421(400)	480		340		---	
182(200)	275	147 (A ₈)	---	210 (A ₅)	---	209 (A ₂)
350(300)	385		---		---	
523(500)	565		390		375	
715(700)	760		600		610	
907(900)	920	171 (A ₇)	760	191 (A ₄)	765	204 (A ₁)



If the mold with the cavity 1.5 mm in height is considered, the corresponding mold for the second shot has a cavity 1.374 mm in height. The cross sections of the molded channels after second shot are shown in Fig. 11 at the position near the far end from the gate. The figure shows cross sections of channels

with the width of 1000, 900, and 500 μm . The thickness inference is also shown under each picture for the channel. Notice that the interference is calculated as the difference between the measured thickness of the substrate and the cavity height of the second shot mod. For the case with a lower value of interference, the cross section of the channel shows a wider open at the surface. This is caused by the original circular fillet at the cross section of the channel in the mold due to the machining process. As the interference is larger, the channel will deform because of the compression on the surface of the substrate as the mold closes. For interference near or above 196 μm , the cross section of the channel deforms more and forms a narrow neck at the middle of the channel. Therefore, an adequate selection of interference is necessary to keep the channel shape for the filling process at the second shot. This selection can be attributed to the control of the part thickness of the first shot and design of cavity thickness for the second-shot mold.

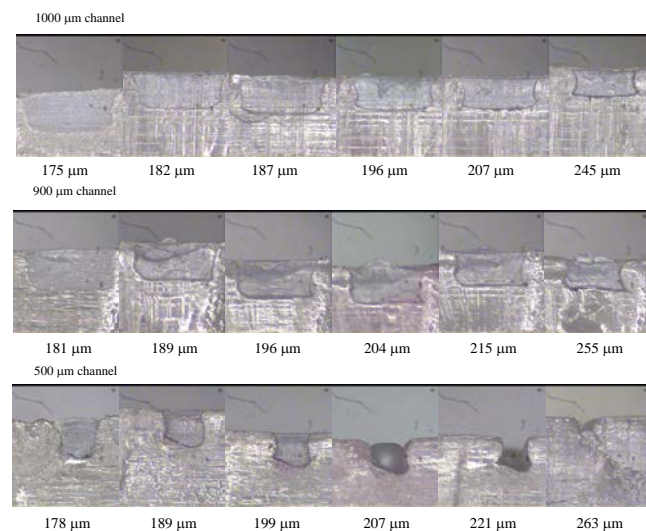


FIG. 11 CROSS SECTION OF THE CHANNELS, 1000, 900, 500 μm IN WIDTH, AND THE THICKNESS INTERFERENCE

Filling Length of the Channels

TABLE 3 THE CHANNEL DIMENSION AT THE MOLDED PLASTIC SUBSTRATE USING THE MOLD WITH CAVITY 90 mm LENGTH

Channel width at the mold	Channel width at the plastic substrate
400 μm	338 μm
500 μm	448 μm
600 μm	539 μm
700 μm	644 μm
800 μm	735 μm
900 μm	875 μm
1000 μm	978 μm

In the filling of the channels in the second shot, most of the channels can be filled completely as the mold cavity is only 14 mm in length. In order to study the capability of the filling length in the second shot, a

mold with larger length in cavity, 90 mm, is constructed. The mold has channels with width from 400 μm to 1000 μm with 100 μm in increment. The resulting channel width of the molded plastics substrate at the first shot is listed in Table 3.

The filling length on the channels of the plastic substrate at the second shot is shown in Fig. 12 for different mold temperature. It can be seen that the mold temperature must exceed 70 $^{\circ}\text{C}$ in order to have a longer filling length. At the second shot, the filling starts as mold closes after the plastic substrate is imbedded into the mold cavity. Therefore, the plastic substrate is actually at the room temperature and cools the filling melt very fast. A higher mold temperature improves the filling of the second shot in the plastic channels. The filling length on the channels of the plastic substrate for different packing pressures shown in Fig. 13 increases with the packing pressure as it increases above 70 MPa. For the channel narrower than 400 μm , the filling length only increases slightly with the packing pressure. In the application for circuit traces, if long trace is necessary, multiple gates are necessary to fill the circuit in the second shot.

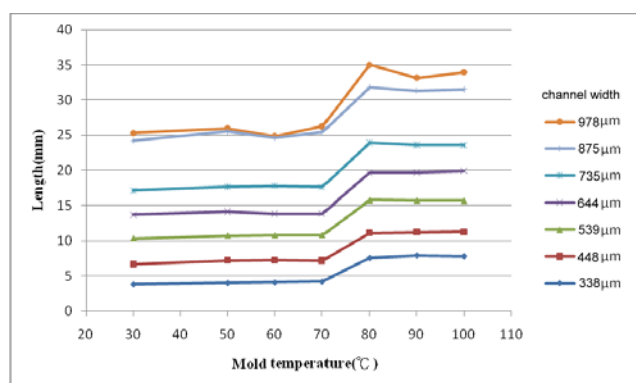


FIG. 12 THE FILLING LENGTH OF CHANNELS ON THE PLASTIC SUBSTRATE FOR DIFFERENT MOLD TEMPERATURES

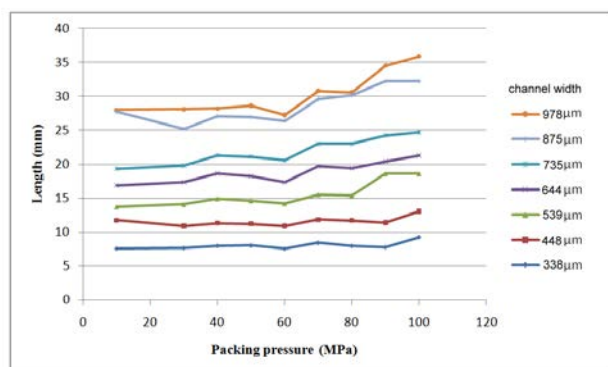


FIG. 13 THE FILLING LENGTH OF CHANNELS ON THE PLASTIC SUBSTRATE FOR DIFFERENT PACKING PRESSURES

Conclusions

Application of micro injection molding technology to

the two-component molding process for the MID fabrication has been investigated. The process involves the first shot of a plastic component with channel patterns on the surface. While the second shot by micro injection molding technology is applied to fill the channel with the plateable plastics. Experiments are designed to mold channels on a plastic substrate with different widths from 200 μm to 1000 μm , and the channel depth is set to be 500 μm . The effects of the micro injection molding process parameters on channel filling of the two-component MID will be investigated. It is demonstrated that the thickness of the substrate will affect the uniformity of the molding part. For a MID component, the molding conditions must be designed carefully to keep the thickness variation below the allowable value (about 100 μm in this case). It is also found from the experiments that the thickness interference might be in the range from 92 μm to 196 μm to have an adequate molding at the second shot. If the interference is too small, the same flash problem will occur. As the interference is too large, the mold compression will destroy the channel entirely.

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